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EFFECTS OF AVIATION ALTITUDES ON SOFT CONTACT LENS WEAR

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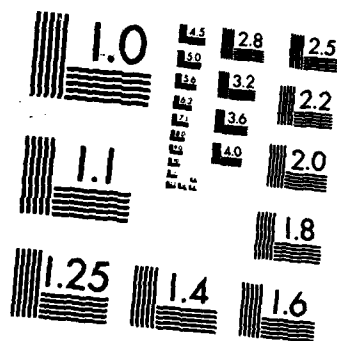
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## EFFECTS OF AVIATION ALTITUDES ON SOFT CONTACT LENS WEAR

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USAF SCHOOL OF AEROSPACE MEDICINE  
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# NOTICES

This progress report was submitted by personnel of the Ophthalmology Branch, Clinical Sciences Division, USAF School of Aerospace Medicine, Aerospace Medical Division, AFSC, Brooks Air Force Base, Texas, under job order 2729-06-02.

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The voluntary informed consent of the subjects used in this research was obtained in accordance with AFR 169-3.

The Office of Public Affairs has reviewed this report, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

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## EFFECTS OF AVIATION ALTITUDES ON SOFT CONTACT LENS WEAR

### INTRODUCTION

Since the cornea is an avascular tissue, its primary open-eye source of oxygen is from ambient air. At sea level, the oxygen partial pressure of this source is about 155 mmHg. This pressure decreases rapidly with increasing altitude. For instance, at an altitude of 10,000 ft, the oxygen partial pressure is reduced to 109 mmHg, and to 59 mmHg at 25,000 ft. A contact lens placed between this source and the cornea must possess sufficient oxygen transport properties to meet an 11- to 19-mmHg oxygen-critical anterior corneal requirement to prevent hypoxia and permit a normal state of corneal hydration (1). Without this critical oxygen level, edema sets in with a resulting loss in corneal transparency (2). Individuals with corneal edema may complain of foggy or hazy vision, discomfort, and injection of the conjunctiva (3). If the edema is severe, breakdown of some of the epithelial cells from prolonged lack of normal corneal metabolism is likely. This breakdown can be detected during a slit-lamp examination with the instillation of sodium fluorescein, where small spots of fluorescein staining will be seen scattered over the central corneal surface (4).

Numerous anecdotal reports, letters, and surveys have appeared in the literature describing discomfort when using contact lenses during aircraft flights (5-8). Many investigators have suggested that the hypoxic air associated with low atmospheric pressures in flight could be the cause of this discomfort (1,9-11). In addition, the dry cabin air has been implicated as a possible causative agent (12). This dryness may induce a resultant dehydration of the soft contact lens (13), with subsequent loss of oxygen transport, since water is the primary conduit for oxygen passage through the lens (14).

Aviation in the U.S. Air Force can be divided into two categories on the basis of aircraft cabin environments. In the first system, the high-performance or fighter-attack-reconnaissance (FAR) aircraft, the aviator's eyes are exposed for short periods to atmospheric pressures equivalent to high altitudes, such as 25,000 ft. In the second system, the tanker-transport-bomber (TTB) aircraft, the aviator's eyes are exposed to lower equivalent altitudes, such as 5,000-10,000 ft, but for longer durations. The different cabin air oxygen concentrations available for corneal metabolism in these two systems are shown in Figure 1. At sea level, air contains 21% oxygen, while in a TTB-type aircraft, such as a C-130, with cabin pressure equivalent to 10,000 ft, the eyes' primary source of oxygen is reduced to 109 mmHg  $O_2$  (14% equivalent oxygen percent at sea level) and in a FAR-type aircraft, such as an F-4, with cabin pressure equivalent to 25,000 ft, the oxygen is reduced to 59 mmHg  $O_2$  (8% equivalent oxygen percent at sea level).

The purpose of this study was to determine for these two type of aircraft environments the consequences of placing a semipermeable (soft) contact lens between the cornea and the reduced levels of oxygen at altitude. Accordingly, soft-contact-lens-wearing subjects were exposed to hypoxic conditions induced by low atmospheric pressures in a hypobaric chamber to simulate FAR and TTB aircraft cabin altitudes. In addition, a preliminary investigation of the



combination of dry air and low atmospheric pressure was included to further simulate actual inflight environments.

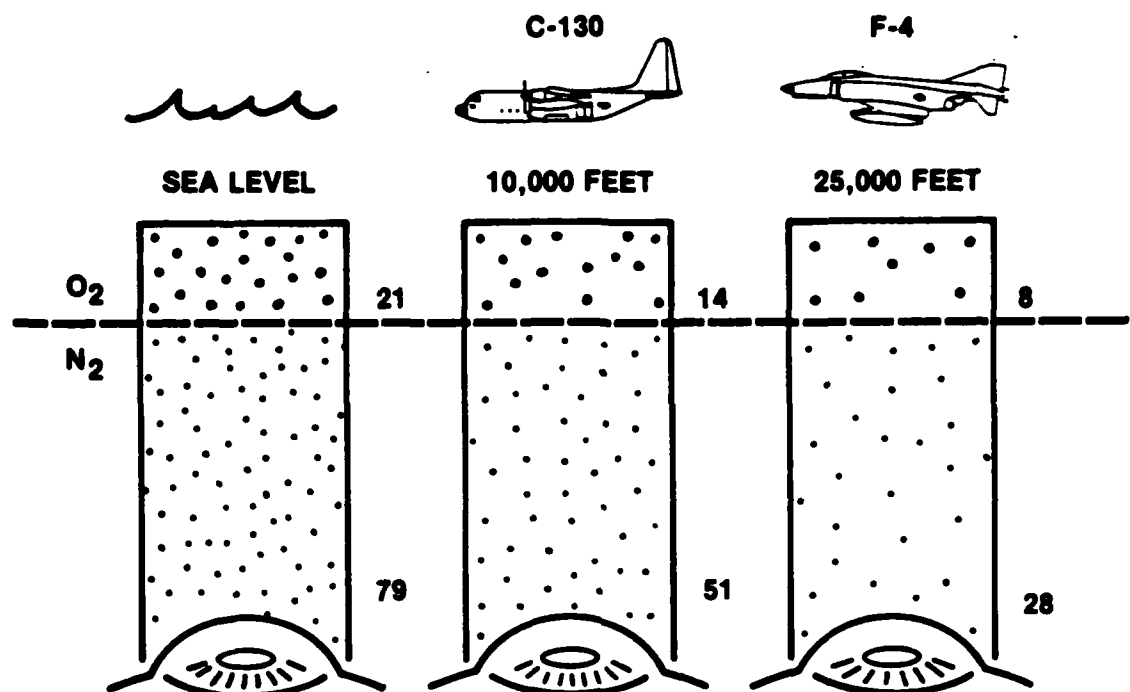


Figure 1. Comparison of the cornea's primary open-eye source for oxygen at three altitudes. Numbers refer to equivalent gas percentages at sea level.

## METHODS

### Fighter-Attack-Reconnaissance Aircraft Simulated-Altitude Study

Ten subjects, from whom informed consent had been obtained, participated in this study which simulated cabin pressures in FAR aircraft. All subjects were fitted with two types of soft contact lenses selected from a range of low-, medium-, and high-water-content contact lenses. One of the subjects was a unilateral contact lens wearer. Each subject was tested 2 times with each of the 2 lens types, for a total of 4 exposures per subject.

Altitude testing was accomplished in a hypobaric chamber where temperature was maintained between 21 deg centigrade (C) and 25 deg C, and relative humidity was maintained between 40% and 50%. Subjects breathed supplemental oxygen through oronasal masks. The ascent rate was 5,000 ft/min, and an atmospheric pressure equivalent to an altitude of 8,000 ft was maintained for 30 min, followed by an altitude of 25,000 ft for 30 min. Descent from 25,000 ft was at a rate of 5,000 ft/min, with 5-min stops every 5,000 ft.

Monocular distant visual acuities (measured on a Bausch & Lomb Visual Testing Apparatus), subjective responses to eye comfort and vision clarity, and slit-lamp examinations were performed preflight, twice at 8,000 ft and 25,000 ft, every 5,000 ft on descent, and postflight.

#### Tanker-Transport-Bomber Aircraft Simulated-Altitude Study

Eight subjects, from whom informed consent had been obtained, participated in this study of 4-h hypobaric chamber flights at an atmospheric pressure level equivalent to 10,000 ft, simulating cabin pressures in TTB aircraft. Each subject was tested in two chamber flights, one while wearing soft contact lenses (Table 1) and the other while wearing spectacles. The soft contact lenses were various types of FDA-approved extended-wear lenses, but were primarily worn on a daily-wear basis. During the flights, temperature was maintained between 21 deg C and 25 deg C, and relative humidity was maintained at 35% to 50%.

TABLE 1. SOFT CONTACT LENS TYPES WORN  
DURING HYPOBARIC CHAMBER TESTING

SUBJECT	LENS
1	55% H <sub>2</sub> O BUFILCON A
2	71% H <sub>2</sub> O PERFILCON A
3	71% H <sub>2</sub> O PERFILCON A
4	55% H <sub>2</sub> O BUFILCON A
5	38.5% H <sub>2</sub> O CROFILCON A
6	38.5% H <sub>2</sub> O CROFILCON A
7	55% H <sub>2</sub> O BUFILCON A
8	71% H <sub>2</sub> O PERFILCON A

Monocular distant visual acuities, as measured on a Bausch & Lomb Visual Testing Apparatus, were recorded every 30 min. Contrast sensitivity measurements were recorded before flight and at 3 and 4 h into flight. These measurements were accomplished on the Vistech<sup>1</sup> near contrast charts, with 5 spatial frequencies of 1.5, 3, 6, 12, and 18 cycles/deg. Each subject graded

eye/lens awareness and vision clarity every 30 min on the grading scale in Table 2. A slit-lamp examination was performed every 30 min to document contact lens fitting characteristics and grade (as shown on the scale in Table 2), the level of conjunctival injection, and tear quality factors, such as the amount of tear debris, wettability of contact lens surface, and the amount of lens deposits. Postflight slit-lamp examinations included the instillation of sodium fluorescein.

TABLE 2. SUBJECT GRADING SCALE FOR SYMPTOMS AND  
EXAMINER GRADING SCALE FOR SLIT-LAMP  
FINDINGS

- 
- 0 = None/normal
  - 1 = Minimal
  - 2 = Moderate
  - 3 = Severe
  - 4 = Extreme/remove lenses

#### Tanker-Transport-Bomber Aircraft Altitude and Low Humidity Study

Four subjects, from whom informed consent had been obtained, participated in this study. Testing was performed in a hypobaric chamber under 4 environmental conditions: (1) ground-level atmospheric pressure levels with 50% relative humidity; (2) ground-level atmospheric pressure levels with 5% relative humidity; (3) 10,000-ft atmospheric pressure level with 50% relative humidity; and (4) 10,000-ft atmospheric pressure level with 5% relative humidity. In each of these 4 conditions, subjects were tested with 3 modes of optical correction: (1) spectacles, (2) high-water-content (71%) soft contact lenses, and (3) low-water-content (45%) soft contact lenses. Chamber temperature was maintained between 21 deg C and 25 deg C.

Monocular distant visual acuities were measured on a Bausch & Lomb Visual Testing Apparatus preflight and every 30 min during the chamber testing. Each subject graded the clarity of vision and eye/lens awareness every 30 min on the scale in Table 2. At the same time intervals, slit-lamp examinations were performed to document contact lens fitting characteristics and to grade the level of conjunctival injection and tear quality. Post-chamber flight testing consisted of slit-lamp examinations, including instillation of sodium fluorescein, and contact lens hydration measurements to check for lens dehydration as a result of low humidity. The hydration measurements were done with a hand-held refractometer that approximated the lens water content from the measured refractive index (15).

---

<sup>1</sup>Vistech Consultants, Inc., 1372 North Fairfield Road, Dayton, Ohio 45432

## RESULTS

### Fighter-Attack-Reconnaissance Aircraft Simulated-Altitude Study

During all 40 trials (10 subjects tested twice each with 2 lens designs), visual acuity was not reduced from baseline levels at any time during the chamber flight. None of the subjects reported any subjective change in vision or any discomfort from the exposure to the low atmospheric pressures. Slit-lamp examinations did not reveal any significant contact lens fitting characteristics or physiological changes from baseline as a result of low atmospheric pressure.

### Tanker-Transport-Bomber Aircraft Simulated-Altitude Study

Visual acuities, measured during the 4-h, 10,000-ft altitude exposures with both contact lenses and spectacles, were 20/20 or better throughout the chamber flight. However, visual acuity line fluctuations did occur (i.e., 20/17-20/20) a total of 19 times (6 of 8 subjects) with contact lenses and 12 times (4 of 8 subjects) with spectacles. Table 3 lists the number of line fluctuations and range for each subject with both contact lenses and spectacles.

TABLE 3. VISUAL ACUITIES DURING HYPOBARIC CHAMBER  
TESTING FOR 4 H AT 10,000 FT

Subject	Number of Visual Acuity Line Changes		Visual Acuity Ranges	
	Contact Lenses	Spectacles	Contact Lenses	Spectacles
1	4	4	20/17 - 20/20	20/15 - 20/17
2	1	2	20/15 - 20/17	20/12 - 20/15
3	2	0	20/15 - 20/17	20/12
4	6	3	20/15 - 20/17	20/15 - 20/17
5	0	0	20/12	20/15
6	0	0	20/15	20/15
7	2	3	20/17 - 20/20	20/17 - 20/20
8	4	0	20/12 - 20/15	20/15

Baseline contrast sensitivity measurements comparing spectacles to contact lenses, as shown in Figure 2, revealed a statistically significant difference ( $P < 0.10$ ) only at the highest spatial frequency, 18 cycles/deg. Contact lens

contrast sensitivities after 3 h and 4 h in hypoxic conditions were not statistically different from baseline values.

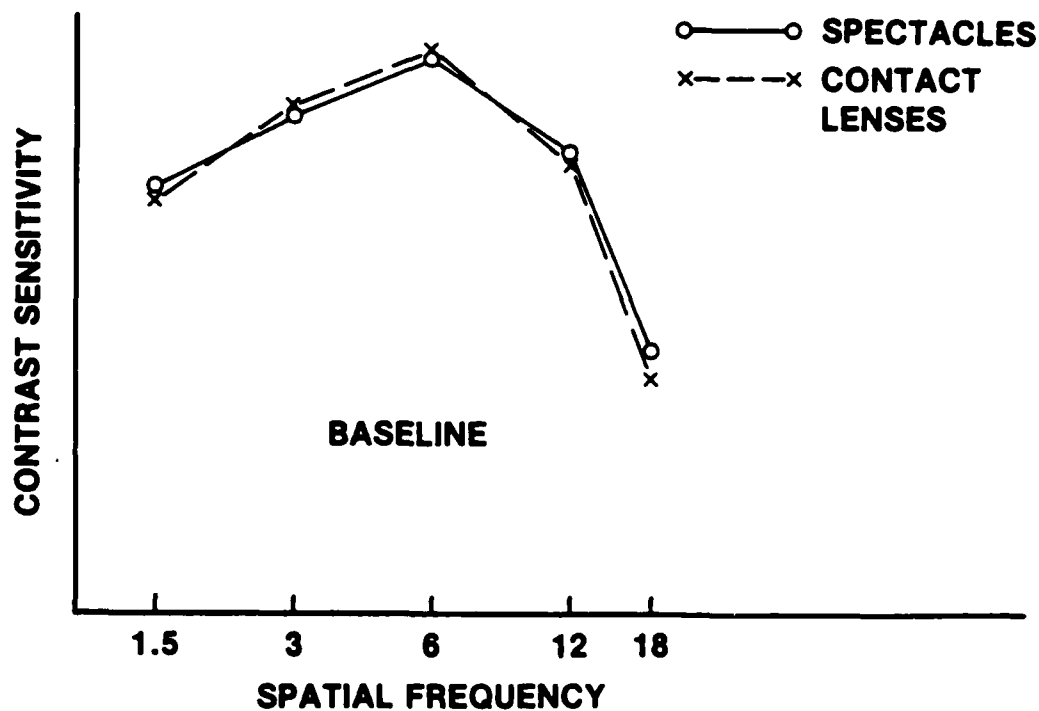


Figure 2. Contrast sensitivity functions for spectacles and contact lenses mean baseline. Spatial frequency is in cycles/degrees.

Subjective grading of vision clarity was unchanged from baseline levels for all subjects during both chamber flights with contact lenses and spectacles. Subject grading of eye/lens awareness showed a trend toward more awareness for the contact lens wearers (Fig. 3).

Slit-lamp examinations of the contact lens wearers showed an initial rise at 1 hr of flight in the examiner-graded level of tear quality factors, and remained nearly the same through the end of the chamber flight (Fig. 4). There was a slower, less-pronounced rise during the flights with spectacles.

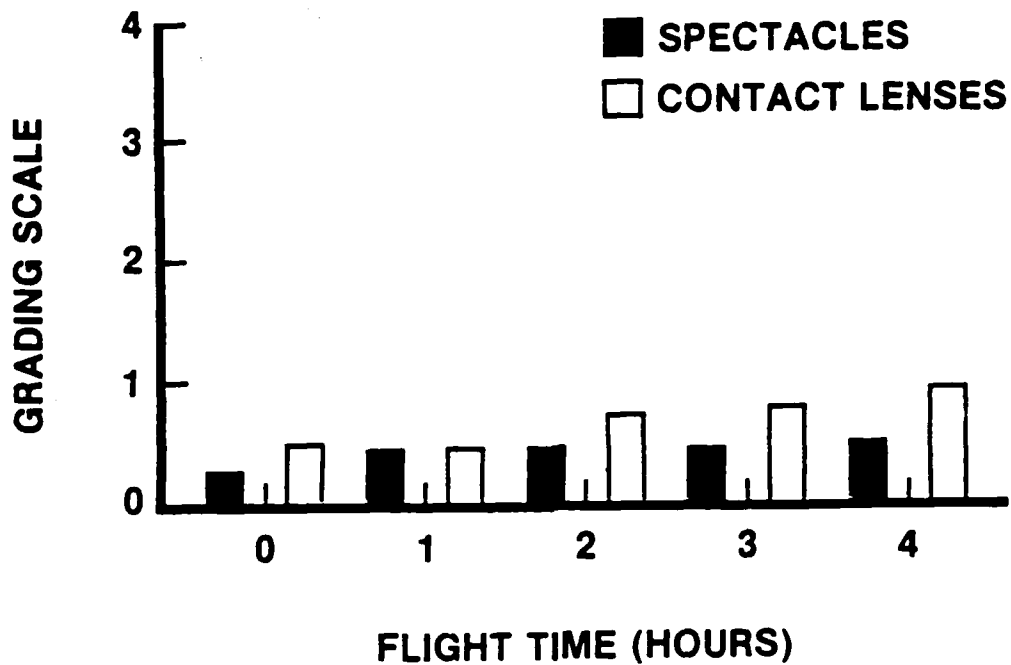


Figure 3. Mean changes in eye/lens awareness reported by the test subjects during the 4-h hypobaric chamber flights.

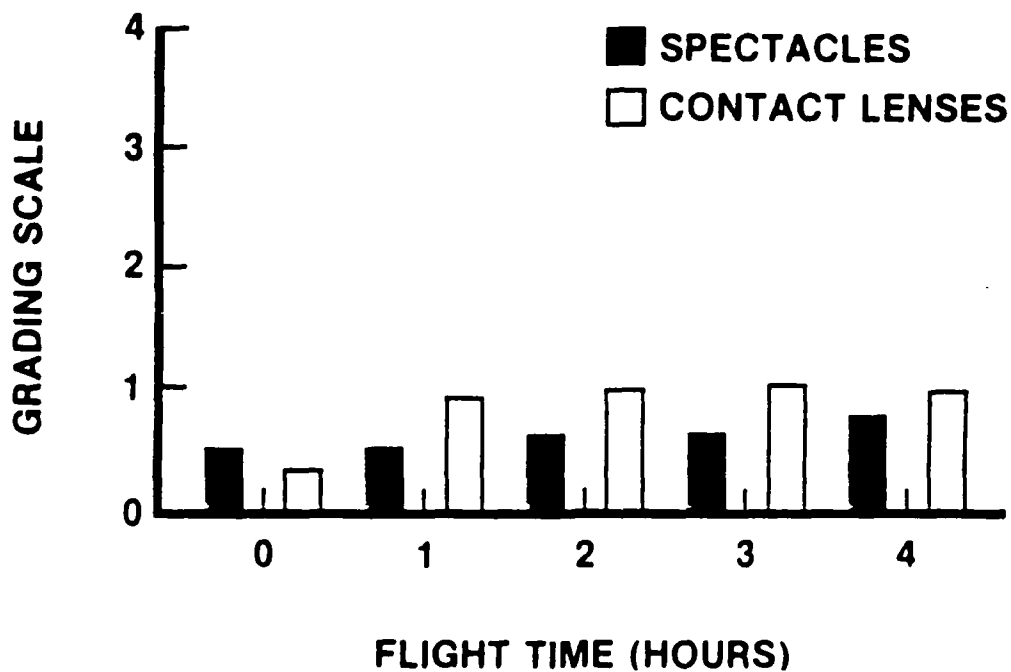


Figure 4. Mean changes in tear film debris during the 4-h hypobaric chamber flights.

Conjunctival injection did increase substantially for contact lens wearers, with 6 of 8 subjects at the Moderate grading scale level at the end of the 4-h period (Fig. 5). Vertical corneal striae were detected in both eyes of one subject with contact lenses at 4 h, and were not noted with spectacle wear in the same subject. Postflight slit-lamp examinations detected superficial corneal sodium fluorescein staining in 5 of 16 eyes from the contact lens flight and 2 of 16 eyes from the spectacle flight.

#### Tanker-Transport-Bomber Aircraft Altitude and Low Humidity Study

Visual acuity for all subjects under all test conditions remained 20/20 or better throughout the chamber flight; however, line fluctuations (i.e., 20/17-20/20) did occur with both contact lenses and spectacles, as shown in Table 4, but more frequently with contact lenses. Exposure to low humidity did not produce any notable changes in the number of fluctuations, whereas spectacle testing showed an increase. Exposure to low atmospheric pressure resulted in higher frequencies of fluctuations for spectacles and both types of contact lenses. Subject grading of their vision clarity was unchanged from baseline levels in all the environmental conditions tested. All subjects graded an increase to grade 1 for eye/lens awareness with contact lens wear in low humidity at ground level and for both humidities at altitude. The grading of eye awareness with spectacles increased to grade 1 for one-half the subjects during both humidity conditions at 10,000 ft.

TABLE 4. NUMBER OF VISUAL ACUITY LINE FLUCTUATIONS

		71% H <sub>2</sub> O Contact Lens	45% H <sub>2</sub> O Contact Lens	Spectacles
Ground level	50% RH	12	17	0
	5% RH	12	13	5
10,000 ft	50% RH	18	21	3
	5% RH	19	19	15

RH = relative humidity

Slit-lamp examinations of contact lens fitting characteristics did not detect any changes during any of the chamber tests. Examiner grading of tear quality factors showed an increase to the minimal level (grade 1) for 75% of the subjects during testing of contact lens wear at ground level with low humidity and with contact lenses and spectacles at altitude with both high and low relative humidity. Grading of conjunctival injection at 10,000 ft showed

large increases for contact lenses, greatest at 5% relative humidity, where 75% of the subjects were grade 2 (Fig. 6). For both conjunctival injection and tear quality, there was not a difference between the low-water-content and high-water-content contact lenses.

Table 5 summarizes the findings of postflight slit-lamp examinations with the instillation of sodium fluorescein, which shows a greater number of eyes with superficial corneal staining from contact lens wear under dry air conditions at ground level and under both high and low humidities at altitude than the considered optimum condition of 50% relative humidity at ground level. Table 6 lists the average contact lens hydration levels at the end of the 4-h tests. The values listed in this table are relative to the full hydration level, as measured with a hand refractometer, of two new 45% and 71% water-content contact lenses. Each new lens was measured 6 times and averaged  $72.6 \pm 0.8\%$  water for the 71% labelled lens and  $43.8 \pm 0.4\%$  water for the 45% labeled lens. Hydration levels for both lens types were reduced 1-1.5% at the lower humidity level, which is statistically significant ( $P < 0.10$ ).

TABLE 5. POSTFLIGHT SODIUM FLUORESCEIN STAINING

	Ground Level		10,000 Ft	
	Relative Humidity			
	50%	5%	50%	5%
45% H <sub>2</sub> O lens	1 (13%)	4 (50%)	3 (38%)	4 (50%)
71% H <sub>2</sub> O lens	1 (13%)	1 (13%)	2 (25%)	4 (50%)
Contact lens total	2 (13%)	5 (31%)	5 (31%)	8 (50%)
Spectacles	0	1 (13%)	0	1 (13%)

TABLE 6. AVERAGE CONTACT LENS HYDRATION LEVEL

	45% H <sub>2</sub> O	71% H <sub>2</sub> O
50% Relative humidity		
Ground level	$94.4 \pm 2.1\%$	$92.0 \pm 3.8\%$
10,000 ft	$94.8 \pm 2.0\%$	$92.6 \pm 3.1\%$
5% Relative humidity		
Ground level	$93.5 \pm 1.5\%$	$90.4 \pm 1.0\%$
10,000 ft	$93.3 \pm 2.4\%$	$91.2 \pm 1.0\%$



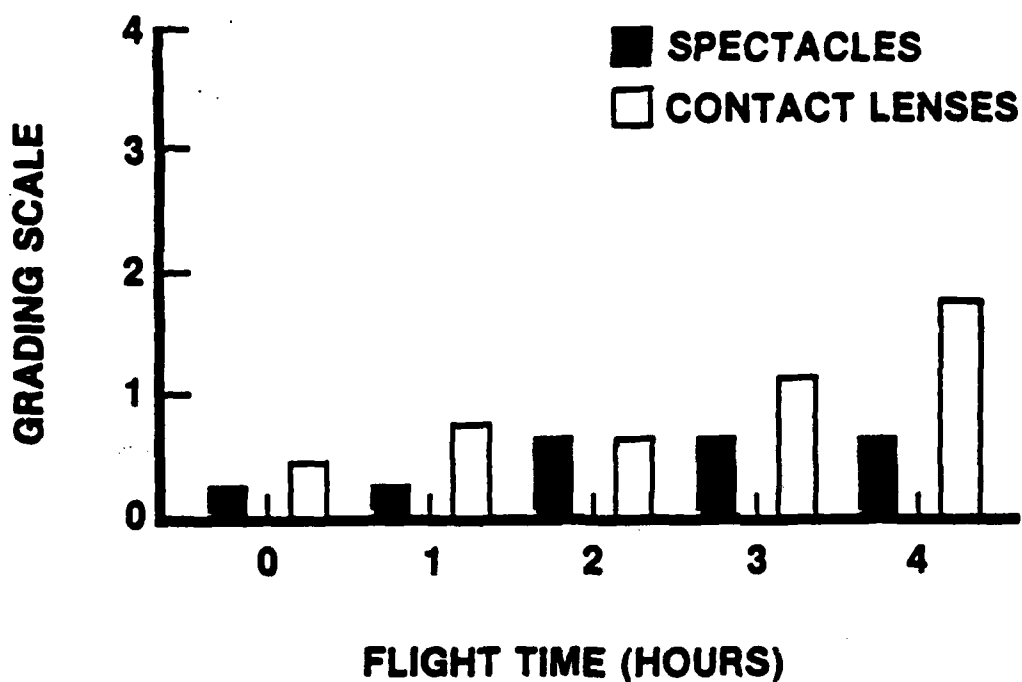


Figure 5. Mean changes in conjunctival injection during the 4-h chamber flights.

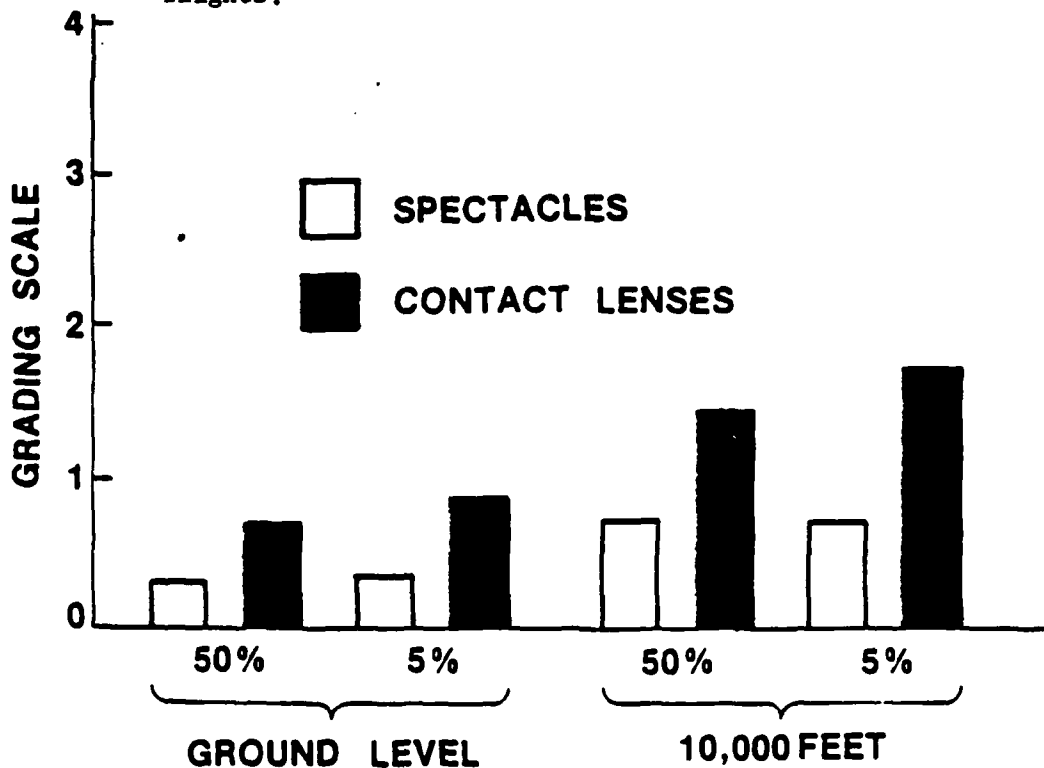


Figure 6. Mean changes in conjunctival injection at the end of 4 hypobaric chamber flights of 50% and 5% relative humidity at ground level and an altitude of 10,000 ft.

## DISCUSSION

Hypoxic levels from low atmospheric pressures that may result in corneal edema with contact lens wear can be predicted through the use of equations provided by Fatt and St. Helen (16). These equations can be used to calculate the oxygen tension at the contact lens-cornea interface, given the oxygen uptake of the cornea and the oxygen transmissibility and thickness of the contact lens. Using these equations with the various air-oxygen tensions at altitudes and contact lens manufacturers' stated values of oxygen transmissibility and thickness, and the Polse-Mandell (1) criterion for the minimum precorneal oxygen to prevent edema, maximum edema-free altitudes can be estimated for contact lens wearers. Figure 7 shows the maximum edema-free altitudes for various contact lenses ranging from low-water-content lenses to high-water-content

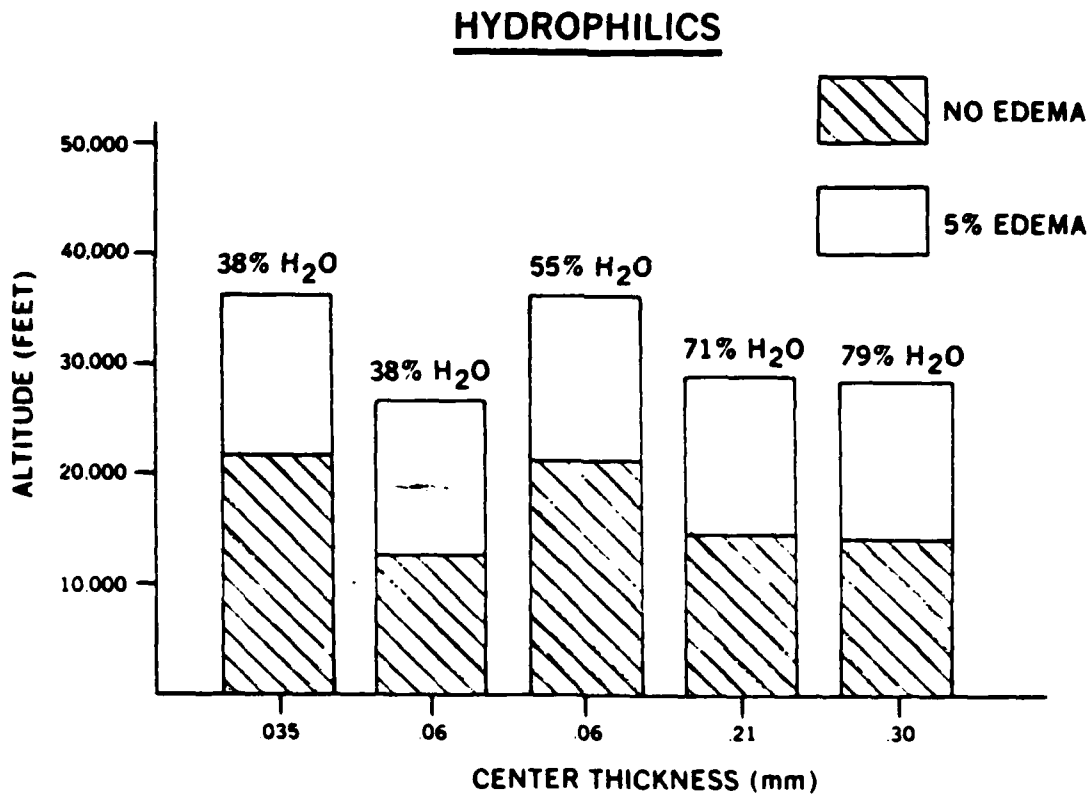


Figure 7. Predicted maximum corneal edema altitudes for various contact lens water contents and their typical center thicknesses.

lenses with their typical center thickness. Also shown in this figure are the altitudes where 5% corneal edema is predicted, based upon anterior corneal oxygen levels found by Holden et al. (17) to produce this level of edema. Five percent corneal edema may be a "physiologically acceptable" level on a short-term basis, since it is only slightly greater than the normal level caused by overnight sleep in eyes without contact lenses (18, 19). As shown in the figure, all lenses listed are predicted to exceed 10,000 ft without hypoxia-induced corneal edema, and none to reach the 25,000 ft level without edema of less than 5%.

To simulate aircrew flying in high-performance aircraft, contact lens wearers using supplemental breathing oxygen were exposed to a high cabin altitude (25,000 ft). In this brief exposure to a low atmospheric pressure and the associated hypoxic conditions to which the eyes were subjected, no significant adverse effects on vision or corneal physiology were detected.

Tanker-transport-bomber-type aircraft cabin atmospheric pressure levels were simulated in a hypobaric chamber with a pressure equivalent to 10,000 ft, an altitude slightly higher than is commonly found in these types of aircraft. Soft contact lens vision was unaffected by this altitude exposure, including when altitude was combined with dry air. Although visual acuity line fluctuations were frequent with contact lenses, they cannot be positively linked to low atmospheric pressure exposure. Fluctuations also were found during spectacle wear, although to a lesser degree, and with contact lenses at ground level. Variable vision has been reportedly common with contact lenses (20), and visual acuity is a subjective measure near threshold; therefore, some individual variation is to be expected. Similarly, contrast sensitivity with contact lenses was unaltered due to low atmospheric pressure. The difference between contact lens and spectacle contrast sensitivities at higher spatial frequencies that was found in this study has been associated with residual astigmatism, uncorrected by contact lenses (21).

Indicators of physiologic stresses on the cornea, such as tear debris, conjunctival injection, and corneal epithelial staining, showed heightened responses at altitude with contact lenses. Conjunctival injection and corneal staining are associated with hypoxia and its induced edema, and therefore may be the result of the low atmospheric pressure, although other factors, such as dry air, may also play a role. A further indication of increased physiologic stress was the detection of vertical corneal striae in both eyes of 1 subject with contact lenses at 10,000 ft. Vertical corneal striae represent significant corneal edema (22), and although edema is not predicted to occur at this altitude, the oxygen demand and swelling response of the cornea is highly individual (1, 23).

The results of this study indicate that the physiologic responses of the cornea to soft contact lens wear are subject to higher levels of manifested stresses at altitude than those found at ground level. However, the higher stress levels occurred without measurable degradation in visual performance. The discomfort of contact lens wear in aviation described by others (5-8) in this study may be represented by the increased eye/lens awareness reported by the study participants, who graded it at a minimal level and found it did not interfere with normal wearing. The lack of visual degradation and significant symptoms with soft contact lens wear during exposure to low atmospheric pressure and when combined with dry air, as in this study, suggests that the soft

contact lenses can be worn during flying. However, it is important to note that exposure was limited, and that with prolonged or repeated exposure, combined with additional aircraft environmental factors the physiologic responses of the cornea may be severe enough to affect vision and preclude the wearing of soft contact lenses during flight.

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